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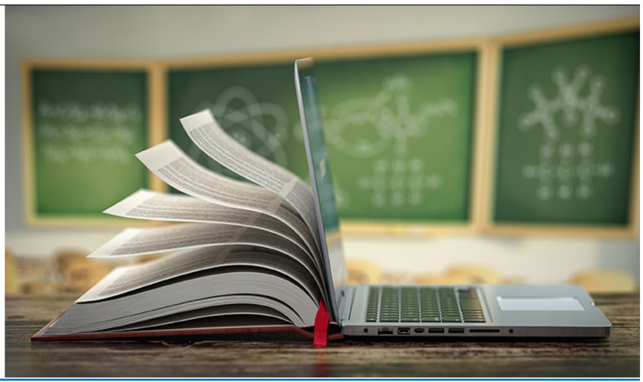

Genetic Forest Typology as a Scientific and Methodological Basis for Environmental Studies and Forest Management

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Abstract. Paper describes key elements of a genetic approach to classification of forest types – one of the original forest typological research directions in Russia summarizes the results of research over the hundred-year period of formation and development of this promising (from the point of view of sustainable management of natural resources) scientific direction. Authors provide a map of current forest type genetic classification use in the Russian Federation, and outline key perspective directions in the development of genetic classifications within a framework of the described approach. Modern genetic forest typology is an interdisciplinary science. It uses forestry, soil science, biogeography, and landscape ecology, allow you to reflect the processes of forest vegetation dynamics in syntaxons and on maps. Therefore, it gives excellent results for systematizing not only primary forests, but also a variety of secondary plant communities with extremely variable composition. Authors believe that there are the following main avenues of genetic approach to forest type classifications development: improvement of forest zoning technologies based upon assessment of environmental factors' quantitative values, including development of spatial models for estimating factor values; development of new automated quantitative assessment methods for forest site conditions and tree stands' parameters using high spatial resolution data obtained from aerial drones; development and verification of the rules for combining forest areas with relatively close parameter values, i.e. with similar forest-growing conditions, in one spatial unit; development and verification of the rules for combining spatial units with relatively different forest-growing conditions into larger units according to applied silvicultural practices; Improvement of existing and development of new forest typological schemes reflecting changes in climate conditions that can be applied for zones with high levels of anthropogenic impacts; development of silvicultural practices and logging technologies considering classification schemes of forest type dynamics; Genetic studies of the populations that compose forest communities. Genetic forest type classification is based upon the origin (genesis) and development of forests. Therefore, genesis studies of forest communities based on genetic analysis of the populations will become the core theme of the future fundamental research in this area.

1. Introduction
Forest degradation occurs on a global scale, and produces undesirable effects on human society and biosphere stability [1, 2]. Importance of environmental and economic role that forests play in sustainable human development concept requires improving existing and developing new approaches for sustainable management of natural resources [3, 4]. A reliable theoretical basis for the classification of natural ecosystems is, therefore, crucial. The problem of designing classifications is complicated by the dynamism of natural ecosystems that continuously adapt to climate changes and human impact. Forecasting forests' development under conditions of human impacts with different nature and magnitude requires a deep understanding of the processes that occur in forest ecosystems, and are generally referred to as forest formation process [5]. Forest management, considering specifics of forest formation process in a specific area, allows successful resolution of economic problems, preservation of forest environment-forming functions, and cost minimization of growing productive forests with characteristics close to the primary forests of an area. The original genetic approach to forest classification serving these purposes was developed in Russia at the beginning of the 20th century. Same as synergetics, the approach was developed around studies of extremely complex and dynamic natural systems. In course of testing various forest ecosystem classification approaches and methods, and solving numerous problems related to the complexity of research objects, it was realized that the best results could be obtained only using an interdisciplinary approach. Therefore, the experience and achievements of genetic forest typology (as a multidisciplinary scientific direction) are of great theoretical value and practical significance [6]. This paper presents the features of genetic approach for forest classification, summarizes research results for over one hundred years of forming and developing this scientific direction that is promising in terms of sustainable natural resources' management, and highlights the prospects for further improvement of the approach.

2. Key elements and principles of genetic forest typology classification
Forest typology in Russia is built upon the scientific and theoretical basis of forest types concept developed by G.F. Morozov [7]. The development was significantly affected by Dokuchaev's genetic soil science and Darwin's evolutional theory. Main principles included: (1) ecological features of tree species, (2) uniqueness of geographical environment, (3) relationship among the plants that developed the ecosystem, (4) human, historical and geological factors, and (5) anthropogenic impact. Morozov considered differences in vegetation occurring due to impacts of biogeographic, biosocial and historical factors, and postulated that forest stability is possible only through consistency of various ecosystem processes with the geographical environment. Morozov also introduced the classification hierarchy including zones, subzones, regions, subregions, forest areas, and forest types. Though all forest typology schools in Russia use the abovementioned basic principles [8, 9], genetic forest typology was the only one that developed them in full.

Genetic forest typology was developed in the course of studying the complex forests of the Russian Far East [10, 11]. It was gradually found that forests are in continuous development, which is reflected in the accumulation of changes in forest structure and habitat. It was also noted that small changes are difficult to notice, but the entire development cycle can be divided into stages. Primary forests in this region have cyclical dynamics, with the length of a full cycle equal to 1500-2000 years [12]. Separate phases in the development of a single forest type demonstrate obvious differences in the structure of all forest layers. It was also found that attribution of a plant community to a given forest type based on vegetation characteristics is extremely difficult. Therefore, it was necessary to establish stable indicators of forest types and develop new principles for classifying dynamic forest communities [12, 13].

The term "genetic classification of forest types" was introduced into forest science in 1923 [8, 9]. The term “genetic” refers to genesis of forest ecosystems, and implies that the most careful attention is paid to succession changes. The heritability of the forest structure is considered at the level of the plant community, not at the level of individual plant species. The main purpose of genetic forest typology is to account for forest dynamic processes in vegetation classification. Features of forest formation process become the main indicators of forest type. Thus, the uniformity of stand composition and other vegetation features are of secondary diagnostic significance. The forest type schemes developed by Ivashkevich were the first example of a successful classification based on a genetic approach.

Genesis and shape of relief elements, illumination, physicochemical properties of parent soil-forming rocks, soils, water regime, and water and mineral nutrition of plants are key indicators of the forest type. Vegetation features serve only as additional elements mainly used to determine the stage and direction of dynamics [8, 13]. In the approach, forest type is considered to be a stage in the forest formation process. Types of plant communities represent separate stages of forest type development. Thus, forest type includes a series of plant community types that replace each other over time [13]. Syntaxonomic units of forest cover are always given with a site type index – a three-digit number defining the position of an area in space, its ecological address. A whole set of habitat criteria must be taken into account when defining and describing the forest type.

Genetic forest typology pays a lot of attention to describing terrain since the latter significantly impacts characteristics of other habitat components. The group of forest site types is the main classification unit that describes environmental conditions of individual forest types, and is determined by large landforms defining regimes of surface and intra-soil water flow, nature of forest soil moisture and other key environmental factors. A single forest site type corresponds with one type of primary forest, and several successional lines of secondary vegetation.

In genetic classification, the vegetation of subordinate layers plays a supplementary part while still being an important indicator of site conditions. Diagnostic criteria are selected from all forest layers.

A forest type name consists of a traditional binary name supplemented by a relief feature and a three-digit index of site conditions. The forest type schemes are regionally developed but share common principles. That allows separate sampling and computer processing of forest types, which have counterparts in different altitudinal belts and subzones [5].

3. Application of genetic forest typology

3.1. Application in forest management

Even the very first attempts of using genetic typology as forestry basis have yielded good results [10,12-14] that stimulated further development of the approach. Application of genetic typology started in different regions of Russia [15-19], and soon became one of the most common approaches in Russia and some regions of the former Soviet Union (Figure 1). Types and groups of forests are used to develop specific rational systems of forest management measures. Timely application of the latter allows achieving potential productivity level of the forests, and managing forest formation process. Genetic typology can become the main approach to the development of sustainable forest management measures, conservation and restoration of vital natural resources. In recent decades, the intensity of using genetic forest typology decreased, but the approach is still a reliable basis for forestry (Figure 1). Modern genetic forest typology is an interdisciplinary science using forestry, soil science, biogeography, and landscape ecology [8].

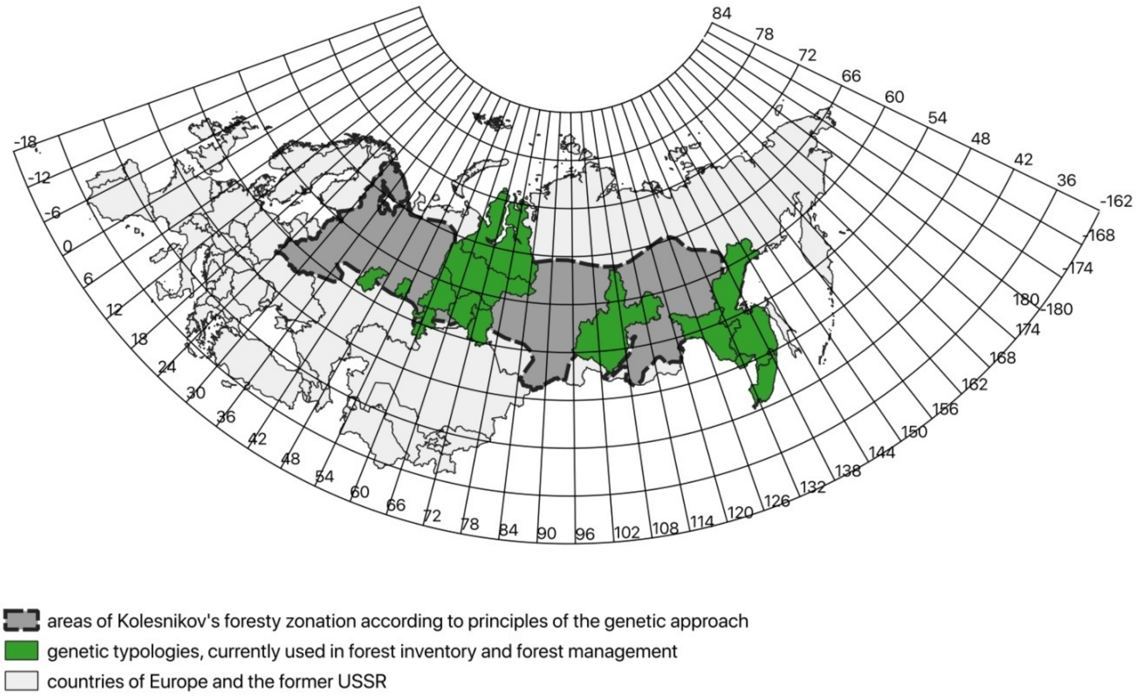

Figure 1. Map of genetic classifications distribution, former USSR, end of the 1970s and current situation

3.2. Studies of human impact on forest
Deforestation and the increasing share of dynamic secondary communities made it necessary to reflect the dynamic trends in forest classification [8]. Boris Kolesnikov [11] introduced the concept of three forest-forming epochs considering the human influence and reflecting forest transformations in classification schemes (Figure 2). These epochs are differentiated by the strength of impact on plant communities, as well as by the forms and technical means of influence. Human impact on forests was negligible in the preagricultural forest-forming epoch, but later on, it increased dramatically and requires close attention. In the era of spontaneous unplanned use of forest resources, digressive-demutational changes became extremely common Intensive forest management complicated reforestation and formation of forest types that fully correspond with zonal and climatic features of the geographical landscape. It is necessary to develop new reliable classification principles that can serve as a reliable basis for forest management. [9, 20, 21].

Reforestation after logging or fires depends upon a combination of factors and has multiple variants [22]. Therefore, various reforestation measures are required for sustainable forest management, not only in different forest types, but also in individual rows of their restoration. In order to give forestry a reliable scientific basis for successful reforestation, Stanislav Sannikov developed a detailed and extremely useful scheme [23] that reflects the main features of taiga reforestation, and has both practical and theoretical value. It also allows understanding the causes of divergence and convergence of plant community structures, and allows making forecasts of reforestation. As a result, Sannikov [24] formulated a hypothesis on the multiplicity of forest ecosystems development lines within a similar habitat, which was actively used in research [20, 21]. Alexander Kryshen [25] and Nina Ulanova [26] made a significant contribution to the issue of felling typology. The research demonstrated that of all the tested approaches to vegetation classification, genetic forest typology produced the best results [25].

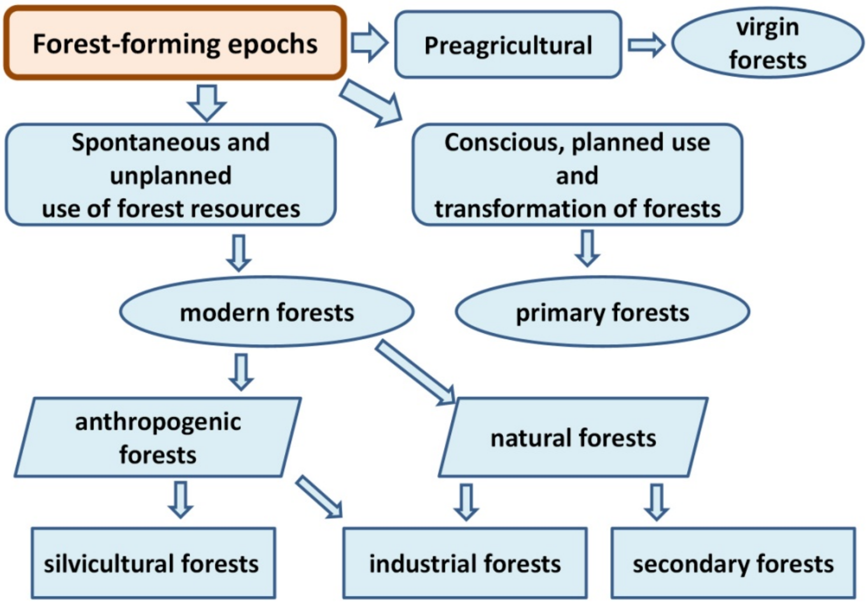

Figure 2. Schema of the human impact on taiga forests in different forest-forming periods

The second urgent and actively discussed modern forest typology problem related to human impacts is the development of dynamic secondary forest type classification approaches. Secondary forests cover large areas, and in most cases, it is impossible to restore primary forests in a natural way. Great contributions to the study of natural secondary forests were made by Martynenko, Baisheva, and Shirokikh [27-29]. Another urgent problem includes the development of a scientific basis for environmental protection in cases of absolutely new forest types that are formed in drained habitats, on abandoned agricultural lands, and in urban landscapes [30].

3.3. Studies of forest climate-driven dynamics

It is now generally recognized that climate-driven forest dynamics should be taken into account when planning for sustainable forest management, which, in term, requires reflecting these processes in forest typological classifications [31-33]. This problem remains mostly unsolved. It is possible to assume that boundaries of forest types will shift and dependencies of forest types from certain habitat conditions will change. It is also possible to assume that forest types will be more vulnerable in extreme conditions. However, to date, these ideas were confirmed only for forest borders in the North and in the mountains [34-36]. It was also currently found that regional climate changes affect the presence and duration of wildfires. Fires have a significant impact on forests, soils, permafrost dynamics, regional climatic conditions and carbon balance [37].

3.4. Cartography and geoinformation technologies

The success of mapping forest types directly depends upon successes in the development of vegetation classification approaches and methods, and forest management requires detailed regional maps of forest types [38]. Forest type maps usually use colour coding that reflects woody plant species. The background colour indicates primary forest type, and the hatching colour reflects secondary forest type. These maps, however, are difficult to read and advances in mapping principles are necessary. Today, forest typological maps are developed using automated site conditions and forest types classification methods, and mapping of forest cover using digital terrain models and remote sensing data [38, 39]. Development of automated data collection methods for composition and structure of stands is a priority in forest science, and multiple studies are available on this problem [40, 41].

3.5. Future development of genetic typologies
Authors believe that there are the following main avenues of the genetic approach to forest type classifications development:

1. Improvement of forest zoning technologies based upon an assessment of environmental factors' quantitative values, including the development of spatial models for estimating factor values.
2. Development of new automated quantitative assessment methods for forest site conditions and tree stands' parameters using high spatial resolution data obtained from aerial drones.
3. Development and verification of the rules for combining forest areas with relatively close parameter values, i.e. with similar forest-growing conditions, in one spatial unit.
4. Development and verification of the rules for combining spatial units with relatively different forest-growing conditions into larger units according to applied silvicultural practices.
5. Improvement of existing and development of new forest typological schemes reflecting changes in climate conditions that can be applied for zones with high levels of anthropogenic impacts.
6. Development of silvicultural practices and logging technologies considering classification schemes of forest type dynamics.
7. Genetic studies of the populations that compose forest communities. Genetic forest type classification is based upon the origin (genesis) and development of forests. Therefore, genesis studies of forest communities based on genetic analysis of the populations will become the core theme of future fundamental research in this area.

4. Conclusions
Genetic forest typology is the original Russian scientific area of the forest science, producing results demanded for practical application. Classification schemes are regional (considering geography of forest ecosystems), but use the same general principles. Genetic forest typology allows reflecting processes of forest vegetation dynamics in syntaxons and on maps, producing excellent results in terms of systematizing both primary forests, and a variety of secondary plant communities with extremely variable composition. Therefore, the genetic forest typology can be considered to be the most promising scientific approach for forest classification.

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